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A sustainable supply chain for organic, conventional agro-food products: The role of demand substitution, climate change and public health

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ABSTRACT

In today's marketplace, conventional agricultural products are produced all around the world due to economic reasons. However, recent environmental challenges such as global warming and climate change has strongly been affected by the high volumes of chemical pesticides and fertilizers used to produce these products. Several published reports have indicated the negative effects of the chemicals used in conventional agriculture as well as the effect of climate change on human health.

The aim of this study is to develop and analyze a multi-objective linear mathematical model for a sustainable supply chain with an agro-food deteriorating product. The product is produced by two different methods, both by organic and conventional means. In this way, we attempt to create a balance between the production and consumption of conventional and organic products in order to achieve three objectives: reducing costs, reducing environmental degradation, and increasing levels of consumer health. Partial backorder for each product, as well as conventional demand substitution by organic products, are taken into account. In order to assess the impact of supply chain operations on public health, we define a new function based on each product's production and consumption amounts as well as the amount of wastes. The developed model is solved by augmented ε-constraint method. Numerical results indicate the important role of supply chain's managers in the formation of sustainable health production and consumption patterns.

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1. Introduction

Reports of the NASA's Goddard Institute for Space Studies (GISS) show that the average temperature of the Earth has increased approximately 0.8 Celsius degrees from 1880 to 2015 (India Water Portal). In addition to the natural consequences of this increase, such as the melting of glaciers, the World Health Organization (WHO) reports that climatic changes over recent decades have probably already affected some health outcomes. This organization estimated that climate change was responsible for roughly 2.4% of worldwide diarrhea and 6% of malaria cases in some middle-income countries in 2000 (www.who.int/globalchange).

In order to cope with the increasing global temperature, climate change, and its consequences, the leaders of 196 countries signed an agreement in December 2015 to replace the Kyoto Protocol. Reducing dependence on fossil fuels, reducing GHG emissions as quickly as possible, achieving net-zero emission in developed and developing countries, and finally, slowing global warming below 2 Celsius degrees are the main objectives of this agreement (The Paris Agreement Summary).

Agriculture plays a vital role in mitigating the consequences of climate changes and global warming. According to Smith et al. (2014b), materials provided as inputs/outputs in the management of agricultural systems usually decompose through bacterial processes, and they emit a considerable amount of CO_2, CH_4, and N_2O into the atmosphere. However, only non-CO_2 agricultural sources are labeled anthropogenic Greenhouse Gas (GHG) emissions. The CO_2 released is considered neutral since it is affiliated with the carbon cycle through photosynthesis. In 2010, the annual non-CO_2 GHG emissions from agriculture are estimated to be 10–12 percent of overall anthropogenic emissions. In that respect, sustainable agriculture is an alternative to expand innovative farming practices

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which are safe and do not degrade the environment (Dordas, 2009).

Sustainable agriculture and organic agriculture are closely interrelated and may sometimes be used alternatively (Rigby and Cáceres, 2001). In fact, organic farming implies an agricultural production method which supports human health and protects both the soil and the larger ecosystems. It relies on biodiversity, ecological processes, and natural cycles. This form of agriculture, which combines science, tradition, and innovation, can promote the environment, and improve the quality of life (IFOAM, 2008; Biodiversity for Sustainable Development, 2016). Organic agriculture is identified as a mitigation strategy to reduce global warming (Müller, 2009). Organic products are produced by farmers who emphasize using renewable resources and preserving the water and soil, and their effort enhances environmental quality for future generations. These products are manufactured in the soil without the use of conventional pesticides, herbicides, or synthetic fertilizers. In other words, these products are manufactured under a natural system. Organic agronomy can be defined as a viable solution to diminish the negative environmental impact of conventional agriculture.

The global market of organic products is valued at around 50 billion Euros. Compared to the rest of the world, demand for these products is highest in the Europe and North America markets. In Europe, Germany has become the most important market with a revenue of more than 7 billion Euros (Mercati, 2016). The potential impacts of organic production can be classified into the following categories:

- Economic impacts: reducing costs, improving farm profitability, conserving energy, and creating a strong rural economy due to increasing employment (Lobley et al., 2005).
- General environmental impacts: a reduction in the pollution of soil, an emphasis on preserving its nutrients, and the creation of more durable agricultural products.
- Agricultural impacts of organic production: creating self-sufficiency in agricultural production, augmenting soil resistance against pests and diseases, and presenting greater uniformity in the quality of food products.
- Social impacts: creating better employment, providing educational opportunities, and improving public health.

Despite these positive impacts of organic production, Tuomisto et al. (2012) identified low yield and nutrient management as the challenges of this production, but proper management and appropriate technologies should help create solutions for these challenges. Despite the challenges, all governments should encourage their farmers to switch to organic farming and to increase public awareness about the benefits of organic products in order to reduce climate change.

Another agricultural fact that must be noted is that approximately one third of food products all around the world, either organic or conventional, are wasted (Gustavsson et al., 2011). According to Gokarn and Kuthambalayan (2017), an increase in GHG emissions (especially Methane), an increase in disposal and waste treatment costs, and an increase in diseases are some of the negative impacts generated from food waste. In order for progress to be achieved on the three pillars of sustainability, serious efforts to reduce food waste must be first pursued and, secondarily, food waste must be managed efficiently.

Despite its practical and theoretical significance, organic and conventional agricultural supply chain planning does not appear to be an in demand topic in the current literature. However, the concerns of agricultural production methods and their effects on public health and climate change cannot be ignored. Further, assumptions of partial backorder and demand substitution have not been pursued in related literature. Hence, to the best of our knowledge, this research work is the first to consider the link among supply chains, sustainability, organic and conventional agricultural products, and public health.

This way, questions which should be addressed in this research are as follows:

- Which impacts have production methods on agro-food supply chains sustainability?
- Can consumer behavior be affected by a consideration of sustainability dimensions?
- Which impacts have demand substitution on agro-food supply chains planning?
- What is the role of agro-food supply chains in shaping healthy consumption patterns?

To answer the above questions, this paper presents a two-echelon sustainable supply chain for an agricultural product with two different production systems (organic and conventional). Because organic products usually cover all the properties of conventional products, we presume that a shortage of the conventional products can be supplied with organic ones. In the first step, a multi-objective Mixed Integer Non-Linear Programming (MINLP) model is developed with the aim of minimizing the total cost, lowering GHG emissions, and maximizing social health. In this way, social health is defined by a novel expression that is a function of individual health and living environment health. Individual health is expressed as a function of conventional and organic consumption rates, while the living environment health function is dependent on the amount of production and waste.

Next, by applying some linearization techniques, the developed MINLP model is converted into a Mixed Integer Linear Programming (MILP) model. In order to solve the developed linear multi-objective model, Augmented ε-constraint (AUGMECON) approach is applied. The two main features of this method are its suitable solving time and the guarantee of finding efficient solutions. Finally, a real two-echelon supply chain for apple is studied for numerical analysis and managerial insights.

The rest of the paper is structured as follows. In section 2, a background of the related areas with the subject of this paper is presented. Green/sustainable supply chains in the food and other industries and papers which have investigated organic products are discussed. Section 3 more clearly identifies the impetus for this paper. Sections 4 and 5 offer the problem description and solution approach, respectively, and Section 6 provides a numerical analysis. Finally, the last section discusses conclusions and directions of future research.

2. Literature review

Sustainable Supply Chain Management (SSCM) considers environmental and social aspects along with economic indices in the Supply Chain (SC), and it is a significant topic for scholars and practitioners (Perry and Towers, 2013; Smith et al. (2014a). Decisions in the area of Green Supply Chain Management (GSCM) take into account both economic and environmental dimensions, while Sustainable Supply Chain Management (SSCM) focuses attention on all three dimensions of sustainability (economic, environmental, and social) (Govindan et al., 2015a,b). Ahi and Searcy (2013) found 22 different definitions for GSCM and 12 for SSCM; ultimately, an accepted expression is that SSCM is an extended mode of GSCM.

An investigation of the papers published in the field of SSCM reveals that the environmental and economic dimensions of sustainability comprise nearly 46 percent of all papers, so these topics

stand out among other research. Only 21 percent of research covers all three sustainability dimensions (Brandenburg et al., 2014). Some social dimensions, like social health, have not been taken into consideration although efforts have been made in recent years to study all three dimensions simultaneously.

Srivastava (2007), Sarkis et al. (2011), Seman et al. (2012), and Min and Kim (2012) presented state-of-the-art work in the field of Green Supply Chain Management (GSCM) from various perspectives. Srivastava (2007) classified his GSCM literature review based on the methodology and problem context, while Seman et al. (2012) reviewed some GSCM practices in developed and developing countries. Sarkis et al. (2011) investigated studies that applied organizational theories to the GSCM. Min and Kim (2012) summarized research trends by investigating the prior literature and they presented a framework for the GSCM studies. Amui et al. (2017) reviewed dynamic organizational capability. In addition, Seuring and Müller (2008), Hassini et al. (2012), Brandenburg et al. (2014), Eskandarpour et al. (2015), Rajeev et al. (2017), and Ansari and Kant (2017) presented a comprehensive review of SSCM.

The following section provides a literature review of the field of green/sustainable Supply Chain Management (SCM). Then, attitudes and incentives to buy organic products are presented in the next subsection.

2.1. Green/sustainable SCM

A summary of some papers published from 2010 to 2017 in the context of GSCM and SSCM is presented in this section. These papers, structured in Table 1, are specified based on criteria such as supply chain characteristics, product characteristics, demand function, shortage assumption, deterioration function, substitution assumption, application, objective functions, modeling, and solution approach. By examining this table, research gaps can be identified clearly. In the following, we explain each column in detail. The abbreviated words found in Table 1 are defined completely in Table 2.

With supply chain characteristics, the direction of the supply chain is one of the main factors considered in GSCM/SSCM literature. The direction of the supply chains is classified as (i) forward, (ii) backward/reverse, or (iii) closed loop. Some researchers, such as Wang et al. (2011), Akgul et al. (2012), Jamshidi et al. (2012), and Mathivathanan et al. (2018), studied sustainability issues in a traditional or forward supply chain; a forward chain is an arrangement of suppliers, producers, wholesalers, retailers, and end customers that are linked together by a forward flow of materials (Stevens, 1989). Conversely, researchers such as Fonseca et al. (2010) and Chaudhary et al. (2017) concentrated on reverse logistics activities in supply chains. In this way, the flow of secondary goods occurs in the direction that starts with end customers and moves to raw material suppliers are considered. Paksoy et al. (2011), Amin and Zhang (2013), Devika et al. (2014a) and Govindan et al. (2015b) considered an integration of forward and reverse/backward processes in a closed loop supply chain. Few works looked into the sourcing side of the supply chain such as, Devika et al. (2014a,b) considered the integration of green practices into the selection of green supplier selection and Kannan (2018) considered the integration of sustainability criteria into the selection of sustainable supplier selection. Alves et al. (2017) described the how supply chain-related contingencies, arising from climate change, are related to changes in the organizational structure of firms.

Product characteristics, consisting of the number and the types of products, are summarized in the product characteristics column of Table 1. Several researchers have proposed their mathematical model for a set of products (Jamshidi et al., 2012; Amin and Zhang, 2013; Devika et al., 2014a,b; Santibañez-Aguilar et al., 2016). Some research provides a model for just a single product (Harris et al., 2014; Brandenburg, 2015), and researchers such as Wang et al. (2011) have extended their model to include both states, a single product and a multiple product.

In Table 1, product types are classified into unlimited lifetime products or deteriorating products. Most authors have extended their mathematical models for unlimited lifetime products (Pinto-Varela et al., 2011; Mallidis et al., 2012; Azadeh et al., 2015). Deteriorating products are defined as those products with a limited useful lifetime and that they deteriorate after a certain time (Sazvar et al., 2014a). There are different approaches to model the deterioration of products mathematically. Soysal et al. (2014) and Govindan et al. (2014) have developed a bi-objective mathematical model for a forward food supply chain. To incorporate the deterioration process into the models, these researchers considered a constraint on the maximum number of periods that these products can be stored. By considering a constant deterioration rate as well as nonlinear holding cost, Sazvar et al. (2014b) proposed a stochastic bi-objective mathematical model for a two-echelon SC. They concluded that by reducing an insignificant portion of the profit, industrial companies can attain an acceptable level of their environmental goals. Interested readers can refer to Sazvar et al. (2013) to become more familiar with quantitative methods to model deterioration of products.

One of the primary supply chains problems that affects optimal policies or planning is how to deal with end customer's demand. In Table 1, end customer's demand is categorized as a certain or uncertain parameter. According to Sazvar et al. (2016), if the demand amount is predefined and given within the planning horizon, it is classified as a certain parameter (Pishvaee et al., 2012; Soysal et al., 2014; Le and Lee, 2013); otherwise, it is considered as an uncertain parameter (Ruiz-Femenia et al., 2013; Pishvaee and Razmi, 2012). Some researchers such as Amin and Zhang (2013) have proposed a mathematical model considering certain demand. Then, by the aid of stochastic programming, they extended their model for an uncertain demand situation.

Two important challenges of today's supply chains that are closely related to the demand function are inventory shortage and demand substitution. However, many studies such as Pishvaee and Torabi (2010), Pinto-Varela et al. (2011), Devika et al. (2014a,b), Azadeh et al. (2015), and Miret et al. (2016) have been developed in GSCM/SSCM literature without considering these two issues to simplify the problem, modeling and calculations. When demand is greater than supply, shortage occurs. Shortage is basically divided into the backordered demand and a lost sale forms. Backordered demand occurs if all unmet demands of the current period adjoin the next period's demand. In a lost sale situation, if customers face an inventory shortage, they prefer to satisfy their demand by other sources. Few researchers such as Sazvar and Sepehri (2016) studied green/sustainable supply chains under a partial backorder situation that is closer to reality. It means that a ratio of unmet demands is backordered and the rest will be lost sales.

Whenever customers face inventory shortages for the product they demand, they may buy another similar product to meet their needs. In this way, demand substitution takes place. According to Li et al. (2006), demand substitution occurs when the demand for a certain type of product is countered with the suggestion to utilize on-hand stocks of other products. As Table 1 shows, demand substitution has been barely studied in the GSCM or SSCM problems. Most studies that considered demand substitution are in the context of traditional inventory or production planning models (Smith and Agrawal, 2000; Rao et al., 2004; Yücel et al., 2009; Dutta and Chakraborty, 2010; Li et al., 2006). However, providing

Table 1
Related recent papers in the context of GSCM and SSCM.

Author(s)	SC. characteristic	Product characteristic	DRF	Shortage	DF	SUB	Application	EC	ENC	SC	Modeling Approach	Solution Approach
Objectives												
Ramudhin et al. (2010)	FOR	MP,ULP	_	NS	Certain	_	Steel	MIN Costs	MIN CO2	_	MO	Goal programming
Pishvaee and Torabi (2010)	CL	SP, ULP	_	NS	Uncertain	_	_	MIN Costs	_	MIN Total delivery tardiness	BO	An interactive fuzzy solution
Fonseca et al. (2010)	Rev	MP, ULP	_	_	Uncertain waste	_	Waste industries	MIN Costs	MIN obnoxious effect	_	BO	An iterative method
Pinto-Varela et al. (2011)	FOR	MP,ULP	_	NS	Certain	_	Pulp and paper	MAX Profit	MIN Environmental Impact	_	MO	Fuzzy-like approach
Wang et al. (2011)	FOR	MP,ULP	_	NS	Certain	_	Procurement center	MIN Costs	MIN CO2	_	MO	Normalized normal constraint
Paksoy et al. (2011)	FOR/Rev/CL	MP,ULP	_	NS	Certain	_	_	MIN Costs	MIN CO2	_	SO	Metaheuristics
Akgul et al. (2012)	FOR	MP,ULP	_	NS	Certain	_	Bioethanol	MIN Costs	MIN GHG	_	MO	ε-constraint
Jamshidi et al. (2012)	FOR	MP,ULP	_	BOS	Uncertain	_	_	MIN Costs	MIN CO, NO2,VOC	_	MO	Hybrid Genetic Algorithm
Mallidis et al. (2012)	FOR	MP,ULP	_	NS	Certain	_	White goods	MIN Costs	MIN total emission	_	MO	Metaheuristics
Abdallah et al. (2012)	FOR	MP,ULP	_	NS	Certain	_	–	MIN Costs	MIN carbon emissions	_	SO	Exact
Pishvaee et al. (2012)	FOR/Rev	SP,ULP	_	NS	Uncertain	_	Medical: needle and syringe	MIN Costs	MIN Environmental Impact	_	MO	Interactive Fuzzy Solution
Pishvaee and Razmi (2012)	FOR	SP,,ULP	_	NS	Certain	_	Medical device	MIN Costs	_	MAX social responsibility	BO	ε-Constraint
Soysal et al. (2014)	FOR	SP, DP	LNP	NS	Certain	_	Beef	MIN Costs	MIN GHG	_	MO	ε-Constraint
Le and Lee (2013)	FOR	MP,ULP	_	NS	Certain	_	Hand tools	MIN Costs	MIN CO2	_	SO	Exact
Ruiz-Femenia et al. (2013)	FOR	MP,ULP	_	NS	Uncertain	_	Chemical products	MAX NPV of profit	MIN Environmental Impact	_	MO	ε-constraint
Amin and Zhang (2013)	FOR/Rev/CL	MP,ULP	_	,NS	Certain, Uncertain	_	Copier remanufacturing	MIN Costs	MAX the use of clean technologies and green materials	_	MO	ε-constraint and weighted sum
Santibañez-Aguilar et al. (2014)	FOR	MP,,ULP	_	NS	Certain	_	Bio-refinery	MAX profit	MIN Environmental Impact	MAX the number of jobs	MO	ε-constraint
Harris et al. (2014)	FOR	SP,ULP	_	NS	Certain	_	_	MIN Costs	MIN CO2	_	MO	Evolutionary with Lagrangian Relaxation
Devika et al. (2014a,b)	FOR/Rev/CL,	MP,ULP	_	NS	Certain	_	Glass	MIN Costs	MIN Environmental Impact	MAX social benefits	MO	Metaheuristics
Sazvar et al. (2014b)	FOR	MP,DP	DR, NLH	PBS	Uncertain	_	Radio-pharmaceutical products	MIN Costs	MIN GHG	_	BO	Compromise programming
Govindan et al. (2014)	FOR	SP,DP	LNP	NS	Certain	_	Perishable foods	MIN Costs	MIN Environmental Impact	_	MO	Hybrid Metaheuristics
Brandenburg (2015)	FOR	SP,ULP	_	LSS	Uncertain	_	Cosmetics product	MAX NPV of profit	MIN Carbon	MAX average service level	MO	Goal programming
Tognetti et al. (2015)	FOR	MP,ULP	_	NS	Certain	_	Automotive	MAX NPV of profit	MIN GWP	_	MO	ε-constraint
Azadeh et al. (2015)	FOR	MP,ULP	_	NS	Uncertain	_	Natural gas	MIN Costs	MIN GHG	_	MO	Interactive fuzzy approach
Mota et al. (2015)	FOR/Rev/CL	MP,ULP	_	NS	Certain	_	Battery producer	MIN Costs	MIN Environmental Impact	MAX social benefits	MO	ε-constraint
Sazvar and Sepehri (2016)	FOR	SP,DP	DR, NLH	PBS	Uncertain	_	Fresh produce	MAX Profits	MIN GHG	MIN labor level change	MO	Interactive Fuzzy approach
Miret et al. (2016)	FOR	SP,ULP	_	NS	Certain	_	Bio-ethanol	MIN Costs	MIN Eco costs	MAX total number of jobs	MO	Goal programming

(*continued on next page*)

Table 1 (*continued*)

Author(s)	SC. characteristic	Product characteristic	DRF	Shortage	DF	SUB	Application	EC	ENC	SC	Modeling Approach	Solution Approach
Santibañez-Aguilar et al. (2016)	FOR	MP,ULP	–	NS	Certain	–	Biorefinery	MAX Net Annual Profit	MIN Environmental Impact	–	MO	ε-constraint
Varsei and Polyakovskiy (2017)	FOR	SP,ULP	–	NS	Certain	–	Wine	MIN Costs	MIN CO2	MAX total social impact	MO	Augmented ε-constraint
Arampantzi& Minis	FOR	MP, ULP	–	NS	Certain	–	Commercial Refrigerators	MIN Total Investment & Operational Costs	Min EI	MIN the negative social impacts	MO	Goal Programming and ε-Constraint
Tsao et al. (2018)	FOR	SP,ULP	–	NS	Uncertain	–	–	MIN Costs	MIN Environmental Impact	MAX the number of social benefits	MO	Interactive Fuzzy Approach
Our proposed model	FOR	SP, DP	DR,NLH	PBS	Certain	*	Agro-Food	MIN Costs	MIN GHG	MAX Public health	MO	Augmented ε-constraint

infrastructures for end customer's demand substitution plays a significant role in the green/sustainable supply chains, especially in supply chains with deteriorating products. It includes working on the customer's culture, applying incentive policies, and conducting integrated planning with consideration of demand substitution. In the case of deteriorating products, if there is a possibility to use a product to meet the demand for other products, the volume of waste and negative environmental consequences may be decreased, while customer satisfaction will rise to some extent.

Regarding modeling approach, studies are categorized into the single-objective or multi-objective problems in Table 1. In the single-objective problem, only one objective is considered as the main criterion and others are embedded in the constraints. Researches such as Paksoy et al. (2011) and Abdallah et al. (2012) studied a green supply chain by considering economic criteria as an objective function and incorporating environmental constraints to form feasible space. However, many researchers have developed multi-objective models and defined each pillar of sustainability as a separate objective (Paksoy et al., 2011; Abdallah et al., 2012; Le and Lee, 2013).

In the majority of studies, the economic criterion is typically defined as total cost, regardless of the time value of money (Ramudhin et al., 2010; Soysal et al., 2014). However, there are also some studies that address Net Present Value (NPV) of SC's cost/profit. Tognetti et al. (2015) has implemented a bi-objective mathematical model to make a trade-off between Net Present Value (NPV) of profit and Global Warming Potential (GWP) of a forward network.

Due to the difficulty in quantifying, the social dimensions of SCs received far less attention when compared to economic and environmental aspects (Brandenburg et al., 2014). Roughly speaking, all studies listed in Table 1 investigated labor and workforce issues as their social objective. For example, Miret et al. (2016) presented an optimal network design problem with minimization of total logistics costs, minimization of eco costs, and maximization of total jobs created. Eco costs were defined as a measure which represents the environmental burden of a product within its life cycle. Arampantzi and Minis (2017) proposed a multi-objective mathematical model using a case study from commercial refrigerators. The first objective function measured the total cost of the supply chain which included operational, emission, and investment costs. The environmental objective related to GHG emissions and waste generation. The third objective, related to social criteria, minimized the negative impact of work opportunities.

Regarding Table 1, with solution approaches, different methods are used to solve GSCM/SSCM problems and they vary from exact approaches to metaheuristics.

Finally, it is obvious that sustainability criteria are one of the main challenges of today's governments, related managers, and practitioners. In this way, researchers have demonstrated the application of their developed models in various industries, including aluminum (Ferretti et al., 2007), pulp and paper (Neto et al., 2008), iron and steel (Zhang et al., 2012; Ramudhin et al., 2010), glass (Devika et al., 2014a,b), automotive (Tognetti et al., 2015), food (Virtanen et al., 2011; Soysal et al., 2014; Govindan et al., 2014; Accorsi et al., 2016) and gas (Azadeh et al., 2015). Brandenburg et al. (2014) focused on different industries and concluded that most GSCM/SSCM studies have been published in the field of technology-related sectors such as energy, electronics, and automotive.

According to Table 1, a growing number of recent studies on supply chain management is dedicated to GSCM and SSCM. Although the mathematical models developed in this regard are mostly effective, to the best of our knowledge, the previous models do not pay attention to public health as an important social aspect,

Table 2
Complete explanations of the abbreviations used in Table 1.

Abbreviation	Guidance	Abbreviation	Guidance	Abbreviation	Guidance
SP	Single Product	CL	Closed Loop	DRF	Deterioration Function
MP	Multi Products	BOS	Backorder Shortage	EC	Economic Criteria
DP	Deteriorated Products	LSS	Lost Sale Shortage	ENC	Environmental Criteria
For	Forward	NS	No Shortage	SC	Social Criteria
Rev	Reverse	DF	Demand Function	ULP	Unlimited Lifetime Product
LNP	Limited Number of Periods	DR	Deterioration Rate	MO	Multi-Objective
BO	Bi-Objective	SO	Single-Objective	NLH	Non-Linear Holding Cost
PBS	Partial Backorder Shortage				

but health is directly influenced by the production activities. In this regard, deteriorating agro-food products that can be produced in organic and non-organic ways deserve more attention. As Table 1 shows, the number of articles that have studied the demand substitution along with the partial backorder in sustainable supply chains is very low. However, demand substitution is one of the ways to achieve relative satisfaction of customers and reduce the shortage cost. In order to cover these research gaps, the current study surveys the problem of "planning a sustainable supply chain for organic, conventional agro-food products by considering the role of demand substitution" so that: i) the methods of agro-food production from organic and non-organic points of view and their impact on climate change are considered; (ii) public health as an important social dimension is incorporated, and (iii) demand substitution coupled with the partial backorder is considered which has led to the formation of new non-linear inventory balance equations. Operation research techniques are used to make them linear, and (iv) some other specifications, such as deterioration of products and non-linear holding costs, are also taken into account to make the model more practical. More details on the motivations for developing this article are described in Section 3.

2.2. Organic products

Many surveys have been conducted in the field of organic products. One common approach is that researchers have tried to find the attributes and factors that motivate customers to buy organic products. Most studies have been done empirically in various countries around the world. Roddy et al. (1996) in Ireland, Magnusson et al. (2001) in Sweden, Lockie et al. (2002) and McEachern and Mcclean (2002) in Scotland, Tsakiridou et al. (2008) in Greece, Tarkiainen & Sundqvist (2005) in Finland, Chang & Zapada (2005) in Australia, Zagata (2012) in Czech Republic, Liu et al. (2013) in China, Wee et al. (2014) in Malaysia, and Teng and Lu (2016) in Taiwan are some examples of the studies conducted to determine customers' attitudes to buy organic products in different parts of the world. Thøgersen (2010) developed a comprehensive model of consumption sustainability factors for the special case of organic food. The results showed various reasons for different organic consumption behavior between countries. Yiridoe et al. (2005) presented a conceptual framework which identified product-related, economic, exogenous factors, and social and demographic variables which affect consumer perceptions toward organic foods. They considered knowledge and awareness of people as main factors that affect the decision to purchase organic products. Aertsens et al. (2009) presented an integrated framework of Schwartz's values theory and the theory of planned behavior on personal determinants related to organic food consumption. These two theories have been used to model organic food choice.

Hansen (2001) introduced and grouped the characteristics of organic foods into general attributes and commodity-specific attributes. General attributes are related to food safety and human health, environmental effects, and farm animal welfare aspects, while commodity-specific attributes consist of visual appeal, freshness, taste, nutritional value, and so forth. Caswell (1998) identified production processes, safety, value, packaging, and nutrition as quality attributes for food organic products. Lea and Worsley (2005) carried out a questionnaire-based research filled by Australian people. Most of them believed that organic foods are better for health and the environment, and that they have good taste.

By doing a comprehensive literature review, Hughner et al. (2007) identified several themes that reflect motivations and deterrents to purchasing and consuming organic foods. Health, taste, local economy support, concern about food safety, concerns over environmental issues and animal welfare, as well as consideration of organic food as fashionable were identified as the main reasons to motivate the purchase of organically-produced food. On the other hand, high price, lack of availability, skepticism of certification boards and organic labels, insufficient marketing, satisfaction with current food sources, and cosmetic defects were determined as the main barriers for buying these products. To overcome the poor marketing barrier, Hemmerling et al. (2015) provided a universal literature review from papers published between January 2000 to December 2011 on marketing research for the consumption of organic products. This study categorized the main positive and negative factors that affect customers' behavior towards organic consumption. In 2013, Schleenbecker and Hamm conducted a comprehensive review about consumers' understanding of the specifications of organic products that were less addressed in previous studies. These specifications include product and packaging design, product labeling, product range, and product support services.

In summary, given the increasing importance of sustainability and the undeniable role of organic products in improving all three dimensions of sustainability, many studies have been conducted to study customers' consumption behavior qualitatively. Two fundamental issues that distinguish this article from existing literature on organic products are firstly that we look at organic products from a supply chain's perspective, not from the customer's viewpoint. Secondly, by applying quantitative mathematical models, the impacts of organic and conventional agricultural production on sustainability criteria are analyzed. Other innovations and contributions are described in detail in the next section.

3. Motivation and contributions

Due to the significant increase in global population, the problem of food supply has become an important challenge for governments. In order to prevent the risks associated with blight and with diseases of crops and livestock, farmers prefer to use chemical fertilizers and pesticides to grow their products. Indiscriminate use

of fertilizers and chemicals sometimes leads to serious problems. These problems include a reduction in the quality and safety of the products, a prevalence of different diseases, and finally, a significant impact on global warming. Using biological fertilizers and organic agriculture, due to their role in enhancing public health and helping to balance the environment, can be an important factor to improve sustainability. Therefore, studies about organic and conventional products and their effects on climate change merits further investigation and research.

To the best of our knowledge, this study is among the first attempts to address a multi-objective linear programming model for a two-echelon agricultural SC taking into account the following outstanding features:

i) Agricultural products by concentrating on the production method. Conventional products, due to the use of chemical fertilizers, have destructive and detrimental effects on society (Biodiversity for Sustainable Development, 2016). However, using organic products can increase social health and help to reduce global warming. Hence, two different production methods, organic and conventional, are considered for a similar agricultural product in this study, and this approach has been less addressed in the past SSCM/GSCM literature.
ii) Agricultural products deterioration. Due to special characteristics such as durability and deterioration, food products need more attention to achieve maximum quality during preparation, storage, transportation, and sale processes. Insufficient attention to these deteriorating products can lead to high costs imposed on the supply chains, imbalance in the demand and supply, climate change and consequently, negative impact on the environment. Regarding Table 1, most studies conducted in the field of GSCM/SSCM have ignored the limited life span of products or their deterioration process. In this study, we used a nonlinear holding cost function and a fixed deterioration rate to model the deterioration process of products.
iii) Demand substitution beside partial backorder. Because of the better features of organic products compared with conventional ones (especially from the viewpoint of sustainability), in this study we assume that a percent (γ) of the consumers will prefer to substitute organics for conventional, if there is no conventional inventory (downward substitution). This way, when consumers face shortage in conventional products, three events will happen: θ% of the unfulfilled demands are backordered and will be answered in the next period. θ'% of them are lost sales and customers prefer to satisfy their requirements from another sources. The rest of the unfulfilled demand may be answered by substitution. Taking into account partial backorder and demand substitution situations simultaneously, our work presents a new form of inventory balance equations, if-then expressions, and brings the model close to reality.
iv) Three dimensions of sustainability: economic, environmental, and social health issues. In this paper, sustainability's triple bottom line pillars are considered as minimization of the total costs, minimization of the GHG emissions, and maximization of the public health level. In the economic objective, various costs such as production, holding, transportation, shortage including backordered and lost sale demand, disposal and substitution costs are considered. We investigate GHG emission levels generated by transportation, production, and disposal operations for both organic and conventional products in the environmental objective. In the social objective and third pillar of sustainability, a novel function is introduced. Public health is defined as a function of individual and living environment health. Individual health is defined as a function of consumption amounts. To be specific, living environment health is considered as a function of production rate and the amount of waste.

4. Problem description

A centralized SC with a single supplier and multiple retailers is considered. The supplier provides a product with two different production methods, namely organic and conventional farming. In each period, depending on the demand of end customers and on-hand inventory level, each retailer will trigger an order to the supplier. Then, the supplier will produce a production batch for a type of product, equal to the total amount of orders received from retailers for that product. After that, the supplier distributes the whole production quantity among retailers, as their order quantities, and holds no inventory in its place. Once the retailer receives the order quantity, it responds to customer's demand. Then, it may face three situations:

i) A retailer's on-hand inventory level is equal to its requirement and no holding, shortage, or substitution cost incurs.
ii) A retailer will face a surplus inventory for any type of product after responding to related requirements. In this case, the additional inventory must be kept in storage, with a nonlinear unit holding cost function defined in the next section. As well, a constant ratio of the on-hand inventories will deteriorate up to the next period.
iii) A retailer will face a shortage of inventory to meet end customer's demands. In this situation, the behavior of customers is different based on the type of products. Regarding organic shortages, partial backorder assumption is considered and two states may occur: θ percent of unsatisfied demands will transfer to the next period and will be backordered, while (1-θ) percent will be lost sale. Regarding conventional shortages, demand substitution may occur as well as partial backordering. In other words, because of the better features of organic products compared to conventional ones, a percent of the unmet conventional demands may prefer to substitute organics for conventional products. So, θ% of the unfulfilled demands is backordered and will be answered in the next period. θ'% of them are lost sale. Then γ% of the rest may be answered by substitution, if there is enough inventory of organic products in stock. Thus, $\gamma(1-\theta-\theta')$% of the unfulfilled customers prefer to substitute organics rather than waiting for the next period or going to another source. This way, the amount of conventional product's demand substitution is equal to the minimum of organic on-hand inventory and $\gamma(1-\theta-\theta')$% of conventional product's shortage. Finally, the rest of unfulfilled demands after substitution will be partially backordered with backorder rate θ.

In Figs. 1 and 2, the responsiveness of the supply chain is shown to the customer demands respectively for conventional and organic products.

The goal of the considered supply chain is to find the optimal value of production and consumption amounts for organic and

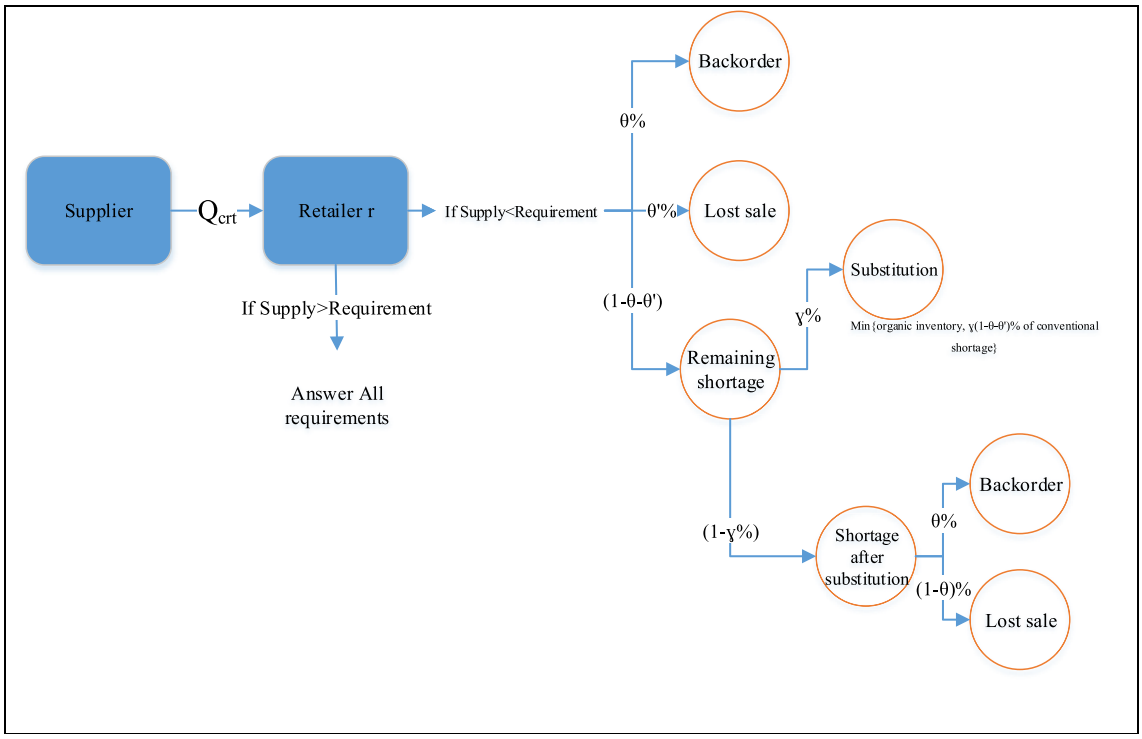


Fig. 1. Response to the conventional product's demands.

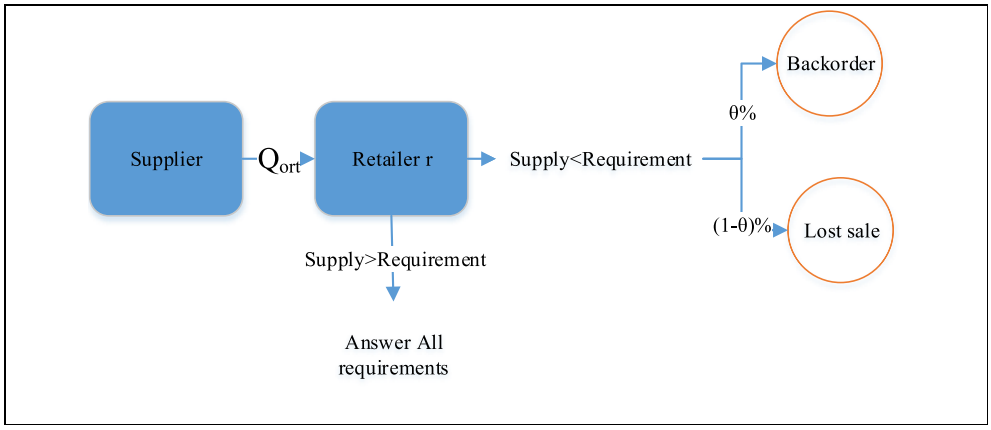


Fig. 2. Response to the organic product's demands.

conventional products. As well, order quantities of each retailer for each kind of product will be determined by concentrating on minimization of total cost, GHG emissions, and maximization of social health.

In this paper, social issues have been included from a new perspective that has been less explored in previous articles. This way, we would like to respond to the question "how can the supply chains' planning affect public health?" Public health refers to the science and art of elongating life, avoiding disease, and improving human health via structured endeavors and conscious choices of individuals, organizations, communities, and societies (Winslow, 1920). We roughly consider public health as a function of individual health and living environment health as follows:

$$Public\ Health = f(individual\ health,\ \ living\ environment\ helath)$$

In the considered supply chain, the two main variables that affect individual health are organic and conventional product consumption. So Individual health is defined as a function as follows:

$$Individual\ health = f(organic\ product\ consumption,\ conventional\ product\ consumption)$$

Test tube researches imply that organic produce may be more health-promoting. Organic berries, for instance, repress the growth of cancer cells better than conventional berries (nutritionfacts.org). The Individual health function is related to the organic consumption directly. In contrast, the use of conventional products may have an adverse effect on public health. According to Baudry et al. (2015), diseases such as hypertension, type 2 diabetes, and

hypercholesterolemia are seen more in non-organic food consumers as compared to organic food consumers. Kesse-Guyot et al. (2017) observed a 31% reduction in the risk of obesity among high consumers of organic food as compared to low consumers.

As well, what contributes to living environment health in the considered supply chain involves the following four factors:

Living Environment health = f (organic production,conventional production, organic product waste, conventional product waste)

According to reports published by the World Health Organization (WHO), an estimated 12.6 million deaths annually are related to unhealthy environments: approximately a quarter of total global deaths. Environmental risk factors, such as climate change, as well as air, water and soil pollution, contribute to more than 100 injuries and illnesses. Contrary to conventional products, the production of organic products as well as the disposal of organic waste may positively contribute to the health of the living environment.

4.1. Assumptions

The following assumptions are considered in the proposed model.

- Demand of each retailer for each product is given.
- The maximum number of products per order is specified for each retailer and each kind of product.
- No production or transportation lead time is considered.
- All products are transported to retailers and no deterioration occurs during transportation.
- A substitution occurs when the demand for conventional product is faced with inventory shortage, and fulfilled through using stocks of organic product. Based on (Li et al., 2006), this study concentrates on downward substitution where product with better features (organic) can be substituted by product with fewer features (conventional product), but not vice versa.
- Nonlinear holding cost functions that are dependent on inventory level of each retailer per period for organic and conventional products are assumed as below, respectively:

$$h_{or} = \begin{cases} h_{or1} & 0 < I_{ort} \le K_1 \\ h_{or2} & K_1 < I_{ort} \le K_2 \\ \\ h_{orm} & K_{m-1} < I_{ort} \le K_m \end{cases} \quad \forall r, t \qquad (1)$$

$$h_{cr} = \begin{cases} h_{cr1} & 0 < I_{crt} \le U_1 \\ h_{cr2} & U_1 < I_{crt} \le U_2 \\ \\ h_{crn} & U_{n-1} < I_{crt} \le U_n \end{cases} \quad \forall r, t \qquad (2)$$

where $h_{or1} < h_{or2} < .. < h_{orm}$ and $h_{cr1} < h_{cr2} < .. < h_{crn}$. $K_1 < K_2 < .. < K_m$ and $U_1 < U_2 < .. < U_n$ indicate inventory intervals of organic and conventional products respectively.

4.2. Notations

The following notations are used to propose a multi-objective mathematical model to solve the described problem.

Indicators:

r:	index of retailers, r ∈{1, …,R}
o:	index of organic product
c:	index of conventional product
i:	index of organic and conventional products, i∈{o,c}
m:	index of organic product's inventory level, m ∈{1, …,M}
n:	index of conventional product's inventory level, n ∈ {1, …,N}
t:	index of time periods, t∈ {1, …,T}

Parameters:

D_{irt} :	Demand for product type-i in retailer r at period t
$I0_{ir}$:	Initial inventory level of product type-i in retailer r
MXO_{ir} :	Maximum order quantity of retailer r for product type-i
π'_{ir} :	Unit backordered cost for product type-i in retailer r per period
π''_{ir} :	Unit lost sale cost of product type-i in retailer r
$SC_i t$:	Supplier's set up cost that is equal to S_{it} if $P_{it} > 0$ otherwise it is equal to zero.
h_{ir} :	Unit holding cost for product type-i in retailer r per period
PC_i :	Unit production cost for product type-i
TC :	Unit transportation cost
DC_{ir} :	Unit disposal cost for product type-i deteriorated in retailer r
SC :	Unit substitution cost for using organic product to fulfill demand for conventional product in each period
GP_i :	GHG emission level generated by producing a unit of product type-i
GT :	GHG emission level generated by transporting a unit of product
GD_i :	GHG emission level produced by disposing a unit of product type-i
Dis_r :	Distance between supplier and r-th retailer
α_{ir} :	Disposal rate of product type-i at retailer r
θ_{ir} :	Backorder rate of product type-i for retailer r
θ'_{ir} :	Lost sale rate of product type-i for retailer r
γ :	Conventional product's demand substitution rate for organic product
λ_i :	Consumption impact factor of a unit product type-i on the health function
β_i :	Deterioration impact factor of a unit product type-i on the health function
μ_i :	Production impact factor of a unit product type-i on the health function
M:	A large number

Decision variables:

$P_i t$:	Production quantity of product type i in period t
IC_{rt} :	Inventory level of conventional product at retailer r in period t
IBS_{rt} :	Inventory level of organic product at retailer r in period t before substitution
IAS_{rt} :	Inventory level of organic product at retailer r in period t after substitution
$ISUB_{rt}$:	Substitution level at retailer r in period t
Q_{irt} :	The flow of product type-i to retailer r in period t
B_{irt} :	Shortage level of product type-i at retailer r in period t
AC_i :	Consumption quantity of product type i

4.3. Mathematical model

The mathematical model will be presented in two steps. In the first step, a multi-objective Mixed-Integer Non-Linear Programming (MINLP) model is developed to model the described problem mathematically. To find global optimal solutions more straightforwardly, in the next step the MINLP model is turned into a Mixed-Integer Linear Programming (MILP) model by applying some mathematical techniques (sub-section 4.3.2). Finally, Augmented ε-constraint method is applied to solve the proposed multi-objective MILP model (Section 5).

4.3.1. Mixed-Integer Non-Linear Programming (MINLP) model

According to assumptions and notations mentioned before, the mathematical model can be formulated as follows:

$$\begin{aligned} MinZ_1 = & \sum_{t,i} SC_{it} + \sum_{i,r,t} PC_i.Q_{irt} + \sum_{i,r,t} B_{irt}.\left(\pi_{ir}.\theta_{ir} + \pi_r^{ir}.\theta_r^{ir}\right) \\ & + \sum_{r,t}\left((1-\theta_{cr}-\theta'_{cr})B_{crt} - SUB_{rt}\right).\left(\pi_c.\theta_{cr} + \pi_r^{cr}.(1-\theta_{cr})\right) + \sum_{i,r,t} .Q_{irt}.TC.Dis_r + \\ & \sum_{r,t} DC_{or}.\alpha_{or}.IAS_{rt} + DC_{cr}.\alpha_{cr}.IC_{rt} + \sum_{r,t} h_{or}.(1-\alpha_{or}).IAS_{rt} + h_{cr}.(1-\alpha_{cr}).IC_{rt} + \\ & \sum_{r,t} SC.SUB_{rt} \end{aligned} \tag{3}$$

$$\begin{aligned} MinZ_2 = & \sum_{t}(P_{ct}.GP_c + P_{ot}.GP_o) + \sum_{i,r,t} Dis_r.GT.Q_{irt} \\ & + \sum_{r,t} \alpha_{or}.IAS_{rt}.GD_o + \alpha_{cr}.IC_{rt}.GD_c \end{aligned} \tag{4}$$

$$\begin{aligned} MaxZ_3 = & (\lambda_o.AC_o - \lambda_c.AC_c) + \sum_{t}(\mu_o.P_{ot} - \mu_c.P_{ct}) \\ & + \sum_{r,t}(\beta_o.\alpha_{or}.IAS_{rt} - \beta_c.\alpha_{cr}.IC_{rt}) \end{aligned} \tag{5}$$

s.t.

$$Q_{irt} \le MXO_{ir} \quad \forall i,r,t \tag{6}$$

$$SC_{it} = \begin{cases} 0 & P_{it} = 0 \\ S_{it} & P_{it} > 0 \end{cases} \quad \forall i,t \tag{7}$$

$$P_{it} = \sum_r Q_{irt} \quad \forall i,t \tag{8}$$

$$\begin{aligned} IBS_{rt} - B_{ort} = & (1-\alpha_{or})IAS_{or(t-1)} + Q_{ort} - D_{ort} \\ & - \theta_{or}B_{or(t-1)} \quad \forall r,t \end{aligned} \tag{9}$$

$$IAS_{rt} = IBS_{rt} - SUB_{rt} \quad \forall r,t \tag{10}$$

$$SUB_{rt} = \min\{IBS_{rt}, \gamma(1-\theta_{cr}-\theta'_{cr})B_{crt}\} \quad \forall r,t \tag{11}$$

$$\begin{aligned} IC_r - B_{crt} = & (1-\alpha_{cr})IC_r + Q_{crt} - D_{crt} - \theta_{cr}\Big(B_{cr(t-1)} + \Big(1-\theta_{cr} \\ & - \theta'_{cr}\Big)B_{cr(t-1)} - SUB_{r(t-1)}\Big) \quad \forall r,t \end{aligned} \tag{12}$$

$$IBS_{rt}.B_{ort} = 0 \quad \forall r,t \tag{13}$$

$$IC_{rt}.B_{crt} = 0 \quad \forall r,t \tag{14}$$

$$AC_i = \sum_r I0_{ir} + \sum_{r,t}(Q_{irt} - \alpha_{ir}.I_{irt}) - \sum_r I_{irT} \quad \forall i \tag{15}$$

$$IBS_{rt}, IAS_{rt}, IC_{rt}, SUB_{rt}, P_{it}, B_{irt}, Q_{irt}, AC_i \ge 0 \quad \forall i,r,t \tag{16}$$

Equation (3) represents the first objective function related to the minimization of total cost which includes setup, production, shortage (backorder and lost sale) before and after substitution, transportation, disposal, holding, as well as substitution costs respectively. Minimization of GHG emissions produced by production, transportation, and disposal processes is shown by Equation (4). In many cases, production of organic products helps the environment in beneficial ways. For these situations, the GHG emission of organic production should be considered as a negative expression. Equation (5) intends to maximize the social health and it consists of i) individual health and ii) living environment health. Individual health (the first term) is directly related to the organic consumption and inversely related to the conventional product's consumption. Living environment health (the second and the third terms) is directly related to the organic production and inversely related to the conventional production. Because deteriorated agricultural products are usually food for insects and animals and assuming $\beta_o$and $\beta_c$that are positive, disposal of organic and conventional products are related to the living environment health function directly and inversely respectively. It is worth noting that there is no limitation on the sign of impact factors in Z_3 and, according to the condition, their sign can be determined.

Equation (6) guarantees that organic and conventional product's order quantities are equal or less than the maximum amount of product flow determined for each retailer per period. Setup cost is defined in Constraint (7). Constraint (8) implies that all products will be transferred to retailers and it shows balance equations for the supplier.

Equations (9) and (10) reflect the balance equations for organic products before and after substitution, respectively. Equation (9) implies that organic inventory before substitution/shortage level at the end of period t is equal to non-deteriorated organic inventory remained from previous period after substitution ($(1-\alpha_{or})IAS_{or(t-1)}$) plus order quantity received in this period (Q_{ort}) minus this period demand (D_{ort}) and backordered demand from previous period ($\theta_{or}B_{or(t-1)}$). According to Equation (11), conventional product's unfulfilled demand can be answered by organics, if organic inventory exists. In this case, the amount of substitution is equal tomin$\{IBS_{rt}, \gamma(1-\theta_{cr}-\theta'_{cr})B_{crt}\}$.

Regarding Equation (12), conventional product's inventory/shortage level at the end of period t is equal to non-deteriorated conventional product's inventory remained from previous period, ($(1-\alpha_{cr})IC_{r(t-1)}$), plus order quantity received in current period Q_{crt}, minus current period's demand (D_{rc_t}) and previous period's backordered demands, $\theta_{cr}(B_{cr(t-1)} + (1-\theta_{cr}-\theta'_{cr})B_{cr(t-1)} - SUB_{r(t-1)})$. The previous period's backordered demands can be calculated as sum of primary backorder before substitution, ($\theta_{cr}.B_{cr(t-1)}$), and backorder amount which has not been answered after substitution, $\theta_{cr}((1-\theta_{cr}-\theta'_{cr})B_{cr(t-1)} - SUB_{r(t-1)})$.

Equation (13) indicates that organic inventory before substitution and shortage level cannot be positive values concurrently. Similarly, Constraint (14) is defined for the conventional product. In order to compute the amount of organic and conventional consumption, Equation (15) is developed. Finally, Equation (16) determines types of variables.

4.3.2. Mixed-Integer Linear Programming (MILP) model

In this section, some linearization techniques are applied to develop the linear form for non-linear expressions, i.e., Constraints (7), (11), (13), (14) and holding costs.

At each period, setup cost,SC_{it}, incurs if production occurs. Binary variables, V_{it}, and Constraint (17) are defined to model setup cost as a linear expression,$S_{it}.V_{it}$:

$$\frac{V_i t}{M} \le P_i t \le M \times V_{it} \quad \forall i,t \tag{17}$$

In Constraint (17), V_{it} is equal to 1 if the production occurs and 0 otherwise.

Regarding Constraint (11), substitution occurs when both of the following conditions occur: i) Shortage of conventional inventory; and ii) having on-hand organic inventory. So, the amount of substitution is equal to $\min\{IBS_{rt}, \gamma(1-\theta_{cr}-\theta'_{cr})B_{crt}\}$. By defining binary variables, C_{rt}, Equation (11) can be transformed to linear expressions as follows:

$$IBS_{rt} - M.C_{rt} \le SUB_{rt} \le IBS_{rt} + M.C_{rt} \quad \forall r,t \tag{18}$$

$$IBS_{rt} \le \gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} + M.C_{rt} \quad \forall r,t \tag{19}$$

$$\gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} - M.(1-C_{rt}) \le SUB_{rt} \le \gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} + M.(1-C_{rt}) \quad \forall r,t \tag{20}$$

According to the non-linear form of holding cost, we use non-negative variables, L_{ortm} and A_{crtn}, as well as binary variables, ρ_{ortm} and χ_{crtn} to formulate this cost as a linear expression, $\sum_{r,t,m} h_{orm}.L_{ortm} + \sum_{r,t,n} h_{crn}.A_{crtn}$. This way, and with regard to organic products, Constraints (26)–(28) should be added:

$$(1-\alpha_{or}).IAS_{rt} = \sum_m L_{ortm} \quad \forall r,t \tag{26}$$

$$\rho_{ortm} \times K_{m-1} \le L_{ortm} \le \rho_{ortm} \times K_m \quad \forall r,t,m \tag{27}$$

$$\sum_m \rho_{ortm} = 1 \quad \forall r,t \tag{28}$$

Similar variables and constraints should be defined for conventional products:

$$(1-\alpha_{cr}).IC_r = \sum_n A_{crtn} \quad \forall r,t \tag{29}$$

$$\chi_{crtn}.U_{n-1} \le A_{crtn} \le \chi_{crtn}.U_n \quad \forall r,t,n \tag{30}$$

$$\sum_m \chi_{crtn} = 1 \quad \forall r,t \tag{31}$$

Eventually, the linear form of the proposed model can be represented as follows:

$$\begin{aligned} MinZ_1 = {} & \sum_{t,i} S_{it}.V_{it} + \sum_{i,r,t} PC_i.Q_{irt} + \sum_{i,r,t} B_{irt}.\left(\pi_{ir}.\theta_{ir} + \pi'^{ir}_{r}.\theta'^{ir}_{r}\right) \\ & + \sum_{r,t}\left((1-\theta_{cr}-\theta'_{cr})B_{crt} - SUB_{rt}\right).\left(\pi_c.\theta_{cr} + \pi'^{cr}_{r}.(1-\theta_{cr})\right) + \sum_{i,r,t}.Q_{irt}.TC.Dis_r + \\ & \sum_{r,t} DC_{or}.\alpha_{or}.IAS_{rt} + DC_{cr}.\alpha_{cr}.IC_{rt} + \sum_{r,t} h_{orm}.L_{ortm} + h_{crn}.A_{crtn} + \\ & \sum_{r,t} SC.SUB_{rt} \end{aligned} \tag{32}$$

$$\gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} - M.(1-C_{rt}) \le IBS_{rt} \tag{21}$$

This way, if $C_{rt}=1$ then $\gamma(1-\theta_{cr}-\theta'^{cr}_{r})B_{crt} \le IBS_{rt}$ and $SUB_{rt} = \gamma(1-\theta_{cr}-\theta'^{cr}_{r})B_{crt}$, otherwise, $\gamma(1-\theta_{cr}-\theta'^{cr}_{r})B_{crt} > IBS_{rt}$ and $SUB_{rt} = IBS_{rt}$.

With respect to Constraint (13), at each retailer's site the organic inventory level before substitution,IBS_{rt}, and shortage level,B_{ort}, cannot take positive values concurrently. Thus, by defining a binary variable, ZO_{r_t}, and Constraints (22)–(23), Constraint (13) will be converted to linear expressions:

$$B_{ort} \le M.ZO_{rt} \quad \forall r,t \tag{22}$$

$$IBS_{rt} \le M.(1-ZO_{rt}) \quad \forall r,t \tag{23}$$

Similarly, binary variables, ZC_{rt}, and Equations (24) and (25) are defined, regarding Constraint (14):

$$B_{crt} \le M.ZC_{rt} \quad \forall r,t \tag{24}$$

$$IC_{rt} \le M.(1-ZC_{rt}) \quad \forall r,t \tag{25}$$

$$MinZ_2 = \sum_t (P_{ct}.GP_c + P_{ot}.GP_o) + \sum_{i,r,t} Dis_r.GT.Q_{irt} + \sum_{r,t} \alpha_{or}.IAS_{rt}.GD_o + \alpha_{cr}.IC_{rt}.GD_c \tag{33}$$

$$MaxZ_3 = (\lambda_o.AC_o - \lambda_c.AC_c) + \sum_t (\mu_o.P_{ot} - \mu_c.P_{ct}) + \sum_{r,t} (\beta_o.\alpha_{or}.IAS_{rt} - \beta_c.\alpha_{cr}.IC_{rt}) \tag{34}$$

s.t.

$$Q_{irt} \le MXO_{ir} \quad \forall i,r,t \tag{35}$$

$$\frac{V_i t}{M} \le P_i t \le M \times V_{it} \quad \forall i,t \tag{36}$$

$$P_{it} = \sum_r Q_{irt} \quad \forall i,t \tag{37}$$

$$IBS_{rt} - B_{ort} = (1-\alpha_{or})IAS_{or(t-1)} + Q_{ort} - D_{ort} - \theta_{or}B_{or(t-1)} \quad \forall r,t \tag{38}$$

$$IAS_{rt} = IBS_{rt} - SUB_{rt} \quad \forall r,t \tag{39}$$

$$IBS_{rt} - M.C_{rt} \le SUB_{rt} \le IBS_{rt} + M.C_{rt} \quad \forall r,t \tag{40}$$

$$IBS_{rt} \le \gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} + M.C_{rt} \quad \forall r,t \tag{41}$$

$$\gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} - M.(1-C_{rt}) \le SUB_{rt} \le \gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} + M.(1-C_{rt}) \quad \forall r,t \tag{42}$$

$$\gamma\left(1-\theta_{cr}-\theta'_{cr}\right)B_{crt} - M.(1-C_{rt}) \le IBS_{rt} \tag{43}$$

$$IC_r - B_{crt} = (1-\alpha_{cr})IC_{r(t-1)} + Q_{crt} - D_{crt} - \theta_{cr}\left(B_{cr(t-1)} + \left(1-\theta_{cr}-\theta'_{cr}\right)B_{cr(t-1)} - SUB_{r(t-1)}\right) \quad \forall r,t \tag{44}$$

$$B_{ort} \le M.ZO_{rt} \quad \forall r,t \tag{45}$$

$$IBS_{rt} \le M.(1-ZO_{rt}) \quad \forall r,t \tag{46}$$

$$B_{crt} \le M.ZC_r \quad \forall r,t \tag{47}$$

$$IC_{rt} \le M.(1-ZC_{rt}) \quad \forall r,t \tag{48}$$

$$AC_i = \sum_r I0_{ir} + \sum_{r,t}(Q_{irt} - \alpha_{ir}.I_{irt}) - \sum_r I_{irT} \quad \forall i \tag{49}$$

$$(1-\alpha_{or}).IAS_{rt} = \sum_m L_{ortm} \quad \forall r,t \tag{50}$$

$$\rho_{ortm} \times K_{m-1} \le L_{ortm} \le \rho_{ortm} \times K_m \quad \forall r,t,m \tag{51}$$

$$\sum_m \rho_{ortm} = 1 \quad \forall r,t \tag{52}$$

$$(1-\alpha_{cr}).IC_{rt} = \sum_n A_{crtn} \quad \forall r,t \tag{53}$$

$$\chi_{crtn}.U_{n-1} \le A_{crtn} \le \chi_{crtn}.U_n \quad \forall r,t,n \tag{54}$$

$$\sum_m \chi_{crtn} = 1 \quad \forall r,t \tag{55}$$

$$IBS_{rt}, IAS_{rt}, IC_{rt}, SUB_{rt}, P_{it}, B_{irt}, Q_{irt}, AC_i, L_{ortm}, A_{crtn} \ge 0 \quad \forall i,r,t \tag{56}$$

$$V_{it}, C_{rt}, \rho_{ortm}, \chi_{crtn}, ZO_{rt}, ZC_{rt} \in \{0,1\} \quad \forall i,r,t,n,m \tag{57}$$

5. Solution approach

In order to solve the developed linear model and to find Pareto solutions, Augmented ε-constraint (AUGMECON) method will be applied. In comparison with the traditional ε-constraint approach, this method has some significant advantages including the guarantee of finding efficient solutions and suitable solving time (Mavrotas, 2009). The AUGMECON method can solve small, medium, or even large-size problems. According to this method, one of the objectives is optimized and other objectives are taken into account as constraints (Balaman et al., 2018).

In other words, we are faced with an objective function and constraints that expressly add surplus or slack variables, which can typically be stated as follows (Mavrotas, 2009):

$$G(x) = \min f_1(x) + eps.\left(\frac{s_2}{r_2} - \frac{s_3}{r_3}\right) \tag{58}$$

s.t.

$$f_2(x) + s_2 = \varepsilon_2 f_3(x) + s_3 = \varepsilon_3$$

$$x \in S$$
$$s_i \in R^+ \quad i = 2,3$$

Where $f_i(x) \quad i = 1,2,3$ are three objective functions, and *eps* is a very small number between 10^{-6} and 10^{-3}. S is a feasible region, and , i = 2,3 $r_i$is the range of the i-th objective function. ε_i is the right hand side of the constrained objective functions (Mirzapour al-e Hashem et al., 2012). These are breakpoints achieved by the division of each objective function range on the number of breakpoints. Researchers such as Akgul et al. (2012), Santibañez-Aguilar et al. (2014), and Tognetti et al. (2015) have used the traditional ε-constraint method, while some others like Mota et al. (2015) applied AUGMECON as the solution procedure.

6. Numerical analysis

In this section, a real two-echelon supply chain for an agricultural deteriorating product, apples, with one supplier and two retailers (A and B) is studied. The supplier produces the product with two different production methods, organic and conventional, in a farmland near Damavand. Then, this product is transported to the retailers in order to satisfy end customer demands. The first (A) and the second (B) retailers have 200 km and 300 km distance from the supplier respectively. The transportation costs for organic and conventional products are equal to 0.015 $/kg/km. Moreover, GHG emissions produced by transporting a unit product are equal to 1 gr/kg/km and 3 gr/kg/km, respectively for organic and conventional products. Since packages of conventional products are heavier than organics, more fuel is consumed during transportation and consequently more GHG is generated.

The planning horizon consists of three weeks (periods). The retailer's initial inventory/shortage is equal to zero. The non-linear holding cost function for organic and conventional products at retailer A is as follows:

$$h_{o1} = \begin{cases} 0.70 & I_{o1t} \le 200 \\ 0.75 & I_{o1t} > 200 \end{cases} \tag{59}$$

$$h_{c1} = \begin{cases} 0.50 & I_{c1t} \le 300 \\ 0.53 & I_{c1t} > 300 \end{cases} \tag{60}$$

In fact, the retailer's warehouse is equipped to hold maximum 200 units of organic products. Holding more than 200 units requires extra equipment to keep the standard holding conditions, and this increases the unit holding cost by 0.05$. The same explanation holds true for the conventional apple.

Similarly, the holding cost at retailer B for the organic and

conventional apple is shown in Equations (61) and (62) respectively:

$$h_{o2} = \begin{cases} 0.72 & I_{o2t} \leq 150 \\ 0.77 & I_{o2t} > 150 \end{cases} \quad (61)$$

$$h_{c2} = \begin{cases} 0.47 & I_{c2t} \leq 300 \\ 0.50 & I_{c2t} > 300 \end{cases} \quad (62)$$

Information on production and set up costs is provided in Table 3. Moreover, GHG emissions of production and disposal operations are presented in Table 4.

According to Table 4, GHG, which emits by production and disposal of organic products, is estimated to be less than conventional ones.

At each period and for each retailer, if on-hand inventory is less than requirement, shortage will occur. For organic products, a part of shortage is backordered and will be answered in the next period. The remaining shortage for each retailer is lost sales.

For conventional products, in addition to backorder and lost sale occurrence, consumers can substitute their needs with organics (the substitute product). Backorder, lost sale, and substitution percentages for retailers A and B are presented in Figs. 3 and 4 respectively.

Unit substitution cost is 0.3$/kg/week for both retailers. This cost includes the charge of damage to the reputation and brand of the supply chain.

Organic and conventional product's backorder costs in retailer A respectively equal to 0.5 and 0.45 $/unit/week and these costs in retailer B are 0.3 and 0.25 $/unit/week respectively. Lost sale costs for organic and conventional products are the same and are equal to 60 and 30 $/unit in retailer A and B respectively.

If supply is greater than demand in a period, inventory level will be positive. In this condition, 20% (DC = 0.1 $/unit) and 25% (DC = 0.1 $/unit) of on-hand organic and conventional inventories are deteriorated in retailer A. Since retailer B has older holding equipment, these rates are increased to 35% (DC = 0.2 $/unit) and 40% (DC = 0.3 $/unit) for organic and conventional products respectively. At each period, each retailer can order maximum 1500 kg of each kind of product.

The formulation of the model and all computations were run with the CPLEX algorithm accessed via IBM ILOG CPLEX 12.2. To solve the proposed model for the aforementioned case, AUGMECON method is used. This way, the first objective function (Z_1) is considered as the main objective and the environmental (Z_2) and social (Z_3) objectives were transferred to the constraints. Then we should obtain the ranges of the second and third objectives separately. In order to determine the grid points ε_i, we divide each range to four equal intervals. So the Pareto solutions are achieved by 25 runs and presented in Table 5. In order to have better insight and better understanding of objective functions trends, two examples of these solutions are displayed in Figs. 5 and 6.

With investigation of the Pareto solutions in Table 5, it can be seen that with an increase of environmental index (ε_2), the optimal amount of environmental objective increases, while optimal total cost is improved. This result is also supported by Fig. 5. Based on Fig. 6, with increasing attention to health index, the economic and social objectives increase.

Due to recent climate, environment, and sustainability challenges, all countries should implement sustainable ideas in their consumption patterns between all segments of their societies.

Table 3
Information on production and set up costs.

Product	PCi ($/kg)	Sit		
		t = 1	t = 2	t = 3
O	2.5	150	180	200
C	1.8	110	130	170

Table 4
Information on GHG emissions of production and disposal.

Product	GP_{it}(gr/kg)			GD_{it}(gr/kg)		
	t = 1	t = 2	t = 3	t = 1	t = 2	t = 3
O	10	10	10	5	5	5
C	70	70	70	25	25	25

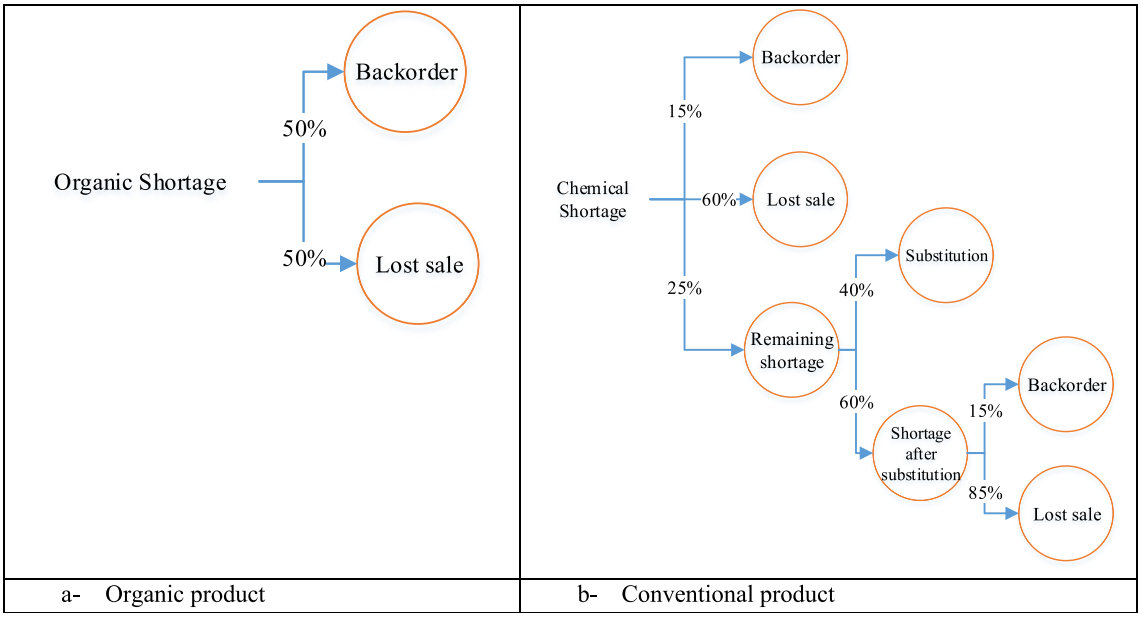


Fig. 3. Backorder, lost sale, and substitution rates during shortage in retailer A.

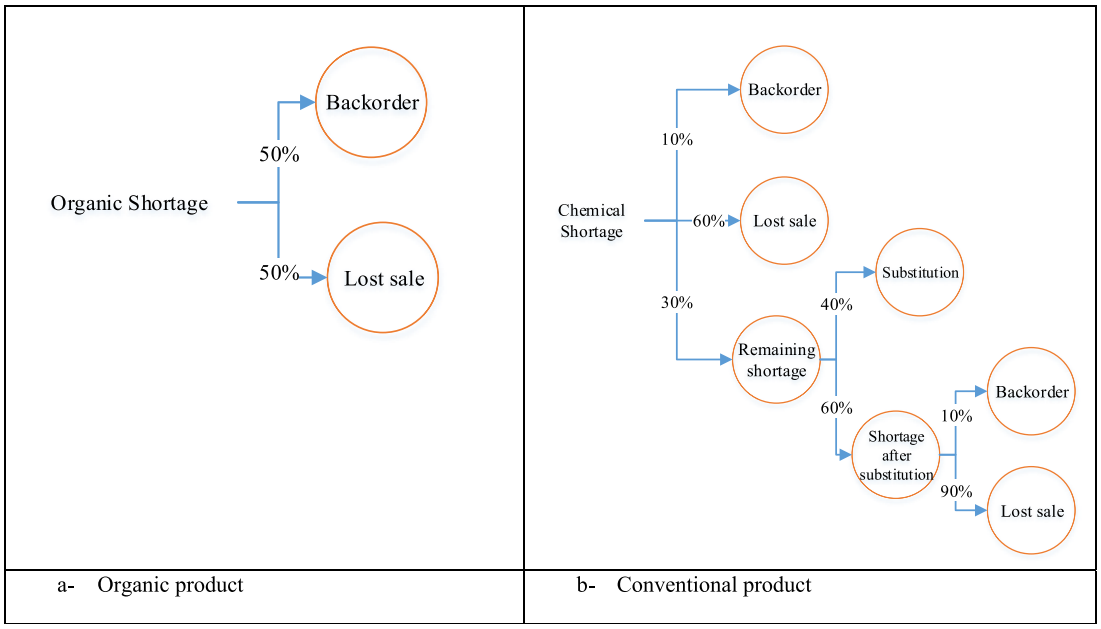


Fig. 4. Backorder, lost sale, and substitution rates during shortage in retailer B.

Table 5
Pareto solutions.

	$\varepsilon_3 = -2764$			$\varepsilon_3 = -895.5$			$\varepsilon_3 = 972.5$			$\varepsilon_3 = 2840.75$			$\varepsilon_3 = 4709$		
	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
$\varepsilon_2 = 0$	177980	0	0	177980	0	0	Infeasible			Infeasible			Infeasible		
$\varepsilon_2 = 811700$	79928	811700	−1550.5	80630	811700	−895.75	115070	811700	972.5	160670	811700	2840.8	Infeasible		
$\varepsilon_2 = 1623400$	60371	1623400	−2504.6	63828	1623400	−895.75	83588	1623400	972.5	120330	1623400	2840.8	Infeasible		
$\varepsilon_2 = 2435100$	42733	2435100	−2764	53643	2435100	−895.75	74042	2435100	972.5	96516	2435100	2840.8	152030	2435100	4709
$\varepsilon_2 = 3246800$	29715	3246800	−2764	48468	3246800	−895.75	69350	3246800	972.5	93990	3246800	2840.8	134700	3246800	4709

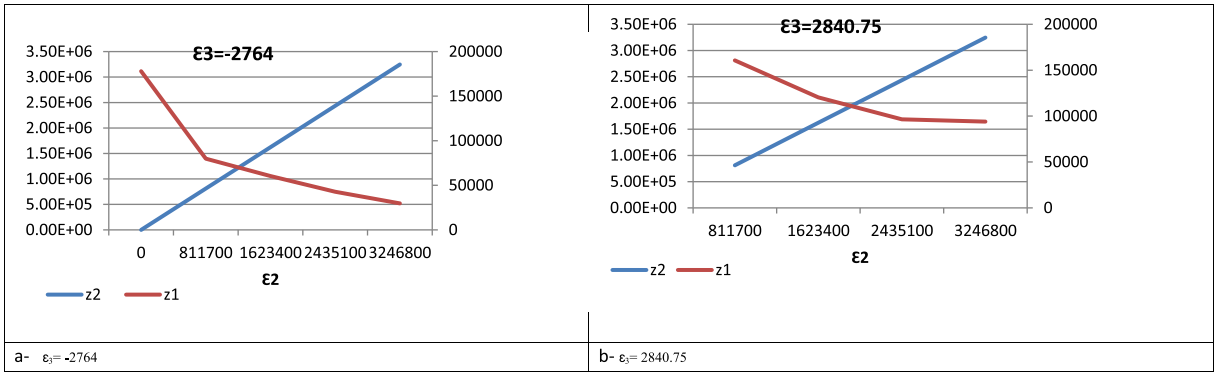
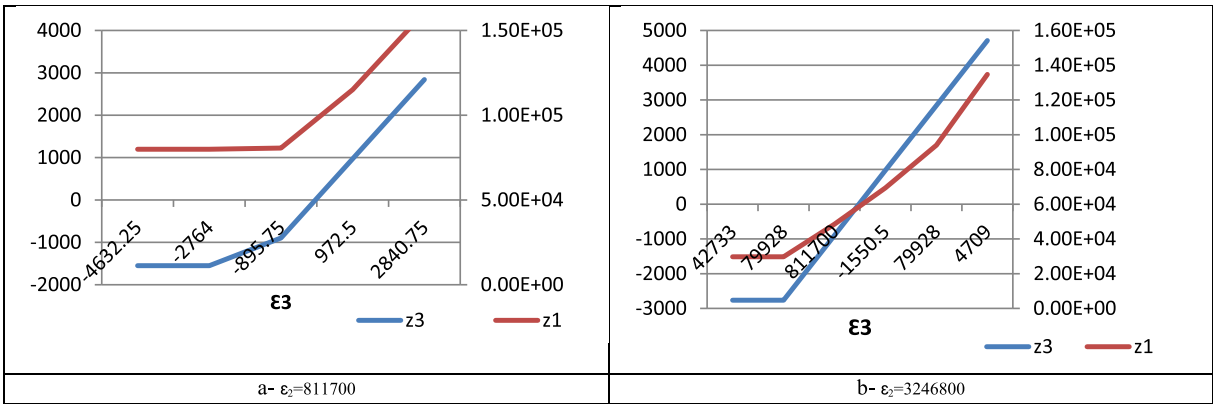


Fig. 5. Two example of Pareto solutions to show the objective function trends through various amounts of environmental index (ε_2).

Supply chain managers play an important role in shaping the sustainable consumption pattern of societies by identifying sustainable plans and programs to offer goods. According to OECD (1999) and Panzone et al. (2013), by definition sustainable consumption is "the use of services and related products which responds to basic needs and brings a better quality of life whilst minimizing the use of natural resources and toxic materials as well the emission of waste and pollutants over the life cycle of the service or products so as not to jeopardize the needs of future generations."

Now, how does our considered supply chain planning affect consumption patterns in the direction of sustainability? Consumption amounts versus environmental and public health indices (ε_2 and ε_3) are reported in Table 6. Moreover, Fig. 7 indicates the organic and conventional product's consumption amounts versus the environmental index (ε_2) for two extreme states $\varepsilon_3 = -2764$ and $\varepsilon_3 = 4709$.

As Fig. 7 shows, when $\varepsilon_3 = -2764$, consumption value for organic products is lower than its value for conventional product for all amounts of ε_2. The consumption functions had indicated major changes when ε_3 increased to 4709 (Fig. 7-b): i) with increased attention to the health index, the amount of organic consumption dominates for all amounts of ε2 and ii) by decreasing

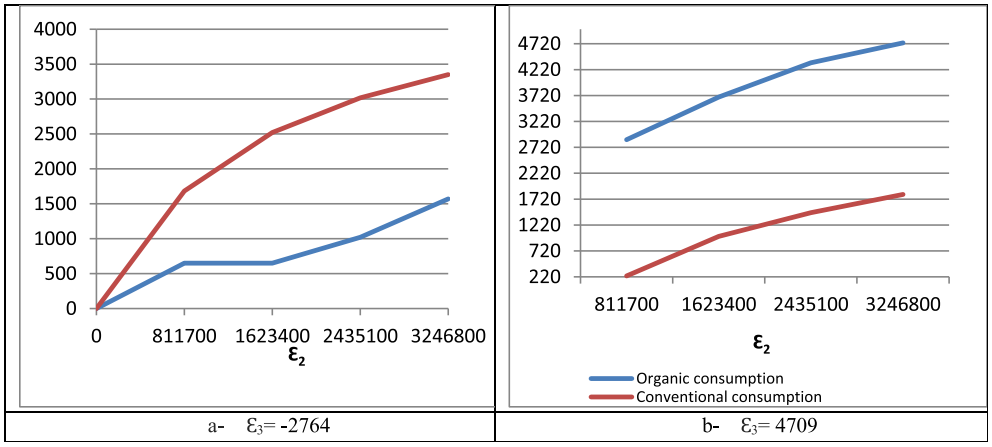


a- ε_2=811700 b- ε_2=3246800

Fig. 6. Two example of Pareto solutions to show the objective function trends through variable amounts of health index (ε_3).

Table 6
Consumption amount vs. Environmental and health index.

	$\varepsilon_3 = -2764$		$\varepsilon_3 = -895.5$		$\varepsilon_3 = 972.5$		$\varepsilon_3 = 2840.75$		$\varepsilon_3 = 4709$	
	o	*C*	*o*	*c*	*o*	*C*	*O*	*C*	*o*	*C*
$\varepsilon_2 = 0$	0	0	0	0	Infeasible		Infeasible		Infeasible	
$\varepsilon_2 = 811700$	650	1683.7	968.09	1391.9	2201.7	1041.2	2867.3	237.53	Infeasible	
$\varepsilon_2 = 1623400$	650	2520.5	1496.3	1744	2821.7	1350	3690.7	1000.8	Infeasible	
$\varepsilon_2 = 2435100$	1020	3017.8	2173.9	2273.8	3408.2	1889.3	4352.4	1458.9	4745.6	211.25
$\varepsilon_2 = 3246800$	1570	3350	2899.5	2969.2	3930.7	2586.2	4736.3	1810.8	5256.4	716.21



a- ε_3= -2764 b- ε_3= 4709

Fig. 7. Consumption vs. Environmental index.

ε_2, the slope of reduction in organic consumption is steeper than the slope of the decrease in conventional consumption.

Regarding Table 6 and Fig. 8, whenever public health criterion is important for supply chain's managers (ε_3 increased), the desire to consume organic products rises. Conversely, consumption of conventional products is reduced.

As an important result, all aforementioned changes in the pattern of consumption functions and the switch to environmentally friendly organic materials takes place without any changes to the end customer's demand function. There is only a consequence of changing the chain managers' approach to address environmental/social issues alongside economic issues, and the demand function remains unchanged. So the obtained results of Table 6 and Figs. 7 and 8 can help decision makers to make the best decision about the programs to promote organic consumption.

Table 7 reports production amounts against ε_2 and ε_3. By comparing this table with Table 6, it can be pointed out that production and consumption have a similar pattern for all cases. This is why supply chain managers and producers can strongly influence the pattern of customer consumption by determining their own pattern of production.

The correlation between consumption and production can also be justified from the perspective of consumers. When there is no desire from customers' side to consume conventional products, the supplier will not tend to produce any conventional products. In other words, growing public awareness about the benefits of organic agriculture can help to reduce the adverse effects of conventional products on environment and public health.

Two indicators, the ratio of conventional consumption to organic consumption (AC_c/AC_o) and the ratio of average conventional production to average organic production ($\overline{P_c}/\overline{P_o}$) are calculated in Table 8. This table's indicators confirm the obtained results

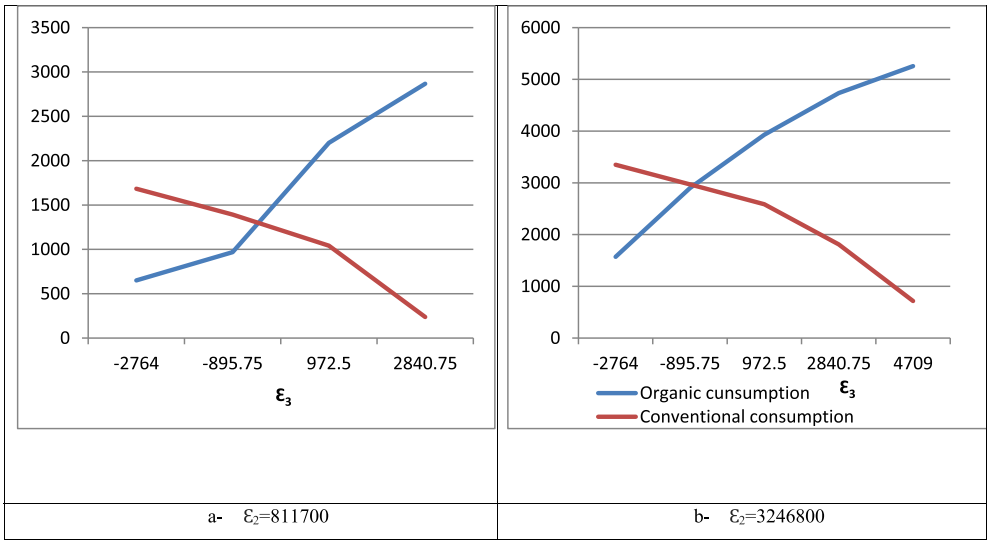


Fig. 8. Consumption vs. social health index.

Table 7
Production amounts vs. Environmental (ε_2) and health index (ε_3).

	$\varepsilon_3 = -2764$		$\varepsilon_3 = -895.5$		$\varepsilon_3 = 972.5$		$\varepsilon_3 = 2840.75$		$\varepsilon_3 = 4709$	
	o	*c*	*o*	*C*	*o*	*c*	*o*	*c*	*o*	*c*
$\varepsilon_2 = 0$	0	0	0	0	Infeasible		Infeasible		Infeasible	
$\varepsilon_2 = 811700$	650	1683.7	968.09	1391.9	2777.4	1041.2	3907.2	237.53	Infeasible	
$\varepsilon_2 = 1623400$	650	2520.5	1496.3	1744	3240.6	1350	5052.1	1000.8	Infeasible	
$\varepsilon_2 = 2435100$	1041.8	2997.9	2291	2273.8	4049.6	1889.3	5739.3	1458.9	6203.1	211.25
$\varepsilon_2 = 3246800$	1570	3350	3334.2	2969.2	5095	2586.2	6267.1	1810.8	6960.6	716.21

Table 8
Consumption and production indicators.

		$\varepsilon_3 = -2764$	$\varepsilon_3 = -895.5$	$\varepsilon_3 = 972.5$	$\varepsilon_3 = 2840.75$	$\varepsilon_3 = 4709$
AC_c/AC_o	$\varepsilon_2 = 811700$	2.590	1.438	0.473	0.083	_
	$\varepsilon_2 = 1623400$	3.878	1.166	0.478	0.271	_
	$_{12}\varepsilon_2 = 2435100$	2.959	1.046	0.554	0.335	0.045
	$\varepsilon_2 = 3246800$	2.134	1.024	0.658	0.382	0.136
$\overline{P_c}/\overline{P_o}$	$\varepsilon_2 = 811700$	2.590	1.438	0.375	0.061	_
	$\varepsilon_2 = 1623400$	3.878	1.166	0.417	0.198	_
	$\varepsilon_2 = 2435100$	2.878	0.992	0.467	0.254	0.034
	$\varepsilon_2 = 3246800$	2.134	0.891	0.508	0.289	0.103

on production and consumption patterns.

The average of each product's order quantity (mean products flow) is calculated in Table 9. Accordingly, with an increase in the environmental index (ε_2) (which means decreasing environmental importance), the total amount of organic and conventional product's orders will increase. However for each value of (ε_2), with the increase of the health index (ε_3), organic order quantity increases. Amounts of organic flow to retailer A, when ε_3 is equal to 4709, is 1500 which is equal to its maximum organics order quantity.

The average amount of shortages is reported in Table 10. Organic and conventional product's shortage levels increase by decreasing ε_2 (increasing environmental importance) to reduced GHG emissions from production, transportation, and disposal processes.

A different story happens about shortage levels by increasing health index. As Table 10 shows, for each value of ε_2, by increasing ε_3, conventional product's shortage amount fluctuates. For example, for retailer A, when $\varepsilon_2 = 1623400$, conventional product's shortage level is reduced from 440.8 to 58.2 with increase of ε_3 from −2764 to 972.5. With the increase of health index from 972.5 to 2840.75, conventional product's shortage will increase to 169.9. The main reason behind this oscillating behavior is substitution of organics for conventional products.

Finally, Fig. 9 indicates the effects of conventional demand substitution rate for organic product (γ) versus waste cost. According to this figure, increasing the amount of γ results in fewer amounts of organic waste and hence its related cost and GHG emissions.

In summary, according to the above numerical analysis, the two main ways that agricultural supply chain managers can contribute to sustainability are

Table 9
The products flow vs. Environmental and health indices.

	Retailer	$\varepsilon_3 = -2764$		$\varepsilon_3 = -895.5$		$\varepsilon_3 = 972.5$		$\varepsilon_3 = 2840.75$		$\varepsilon_3 = 4709$	
		o	*C*	*o*	*c*	*o*	*C*	*o*	*C*	*o*	*c*
$\varepsilon_2 = 0$	A	0.0	0.0	0.0	0.0	_		_		_	
$\varepsilon_2 = 811700$		216.7	0.0	216.7	106.0	925.8	0.0	1302.4	0.0	_	
$\varepsilon_2 = 1623400$		216.7	0.0	216.7	282.1	774.9	305.3	1500.0	184.0	_	
$\varepsilon_2 = 2435100$		216.7	123.3	412.0	351.7	980.9	369.0	1500.0	413.1	1500.0	567.7
$\varepsilon_2 = 3246800$		216.7	306.7	789.5	321.9	1360.6	337.8	1500.0	589.0	1500.0	820.2
$\varepsilon_2 = 0$	B	0.0	0.0	0.0	0.0	_		_		_	
$\varepsilon_2 = 811700$		450.0	111.2	450.0	14.0	347.1	0.0	79.2	0.0	_	
$\varepsilon_2 = 1623400$		450.0	390.2	450.0	131.3	450.0	0.0	333.6	0.0	_	
$\varepsilon_2 = 2435100$		450.0	556.0	450.0	307.9	450.0	179.8	450.0	36.3	70.4	0.0
$\varepsilon_2 = 3246800$		450.0	666.7	450.0	539.7	450.0	412.1	450.0	153.6	238.7	0.0

Table 10
Shortage level with increase of environmental and health indices in retailer A.

	Retailer	$\varepsilon_3 = -2764$		$\varepsilon_3 = -895.5$		$\varepsilon_3 = 972.5$		$\varepsilon_3 = 2840.75$		$\varepsilon_3 = 4709$	
		o	*C*	*o*	*c*	*O*	*c*	*o*	*C*	*o*	*C*
$\varepsilon_2 = 0$	A	283.3	440.8	0.0	440.8		_	_		_	
$\varepsilon_2 = 811700$		0.0	440.8	0.0	255.3	0.0	440.8	0.0	440.8	_	
$\varepsilon_2 = 1623400$		0.0	440.8	0.0	63.8	0.0	58.2	0.0	169.9	_	
$\varepsilon_2 = 2435100$		0.0	225.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\varepsilon_2 = 3246800$		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$\varepsilon_2 = 0$	B	512.7	728.5	512.7	728.5		_	_		_	
$\varepsilon_2 = 811700$		0.0	601.0	0.0	712.5	102.9	728.5	412.0	728.5	_	
$\varepsilon_2 = 1623400$		0.0	284.3	0.0	573.9	0.0	722.6	116.4	725.8	_	
$\varepsilon_2 = 2435100$		0.0	110.7	0.0	375.5	0.0	519.1	0.0	681.5	422.6	722.6
$\varepsilon_2 = 3246800$		0.0	0.0	0.0	126.9	0.0	259.1	0.0	548.7	221.8	722.5

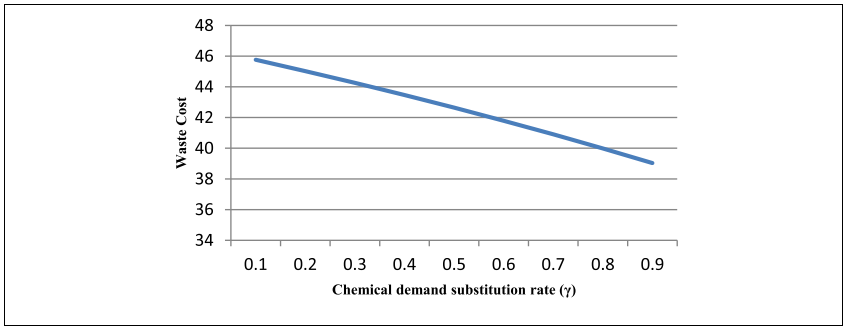


Fig. 9. Effect of conventional product's demand substitution on organic waste.

i) They can have an effect on the demand pattern in the direction of sustainability especially by marketing activities. According to the obtained numerical results, it can be concluded that increasing the conventional demand substitution rate for organic product (γ) leads to an increase in organic/environmentally friendly food consumption, a reduction in the level of conventional product's shortage, and a reduction in waste volumes. Of course, all this will happen if there are enough on-hand inventories of organic products in warehouses.

Increasing (γ) can be interpreted as a change in the demand pattern towards organic food consumption. However, most consumers are not keen to change their lifestyle, including food habits, in practice. In order to alter consumption habits (demand pattern), the whole food value chain (from farm to fork) needs to be involved (Tjärnemo and Södahl, 2015). This way, supply chain planners are important actors in the development of a more sustainable food system. They have the potential to promote and encourage consumers to buy sustainable foods by effective culture and marketing practices. According to the World Business Council for Sustainable Development (WBCSD) business managers can help consumers to discover, select, and utilize sustainable products/services by presenting information, ensuring availability and affordability, and setting the appropriate tone through marketing procedures (http://wbcsdservers.org).

ii) Secondly, managers can modify the production pattern in the direction of sustainability: As Figs. 7 and 8 show, by focusing on a sustainable production plan, consumption patterns will move in the direction of sustainability. The issues such as environmentally friendly production, reducing food wastes in warehouses, not using pesticides or antibiotics and so forth relate closely to the concept of Corporate Social Responsibility (CSR). CSR is the continuous commitment by businesses to act

ethically, contribute to economic development, and improve people's quality of life (Pino et al., 2016). Obtained numerical results confirm that organic production is associated with the improvement of both environmental and social objectives. Therefore, these goals correspond easily to the corporate responsibility of the agricultural industry.

In order to make organic farming economically attractive, the role of governments should not be ignored. Organic food has to gain a significant place in national and international strategies of governments especially in developing countries. Government supports, such as providing infrastructures, subsidies, etc. definitely lead to an increased attraction of farming organically.

7. Conclusions

This paper takes a mathematical programming approach to examine the impact of agricultural supply chain planning on some recent challenging phenomena such as global warming, climate change, and social health. One of the main contributions of the proposed model is considering downward demand substitution for agro-food organic/conventional products. Public health level is also incorporated in the proposed model which has not considered in related works. Considering assumptions such as product deterioration, demand substitution, and partial backorder result in new non-linear forms of constraints/inventory balance equations. With the help of linearization techniques, a multi-objective linear model was finally developed which has been solved by AUGMECON method.

From numerical analysis, it has been concluded that apart from strategic plans, supply chain's tactical plans play a significant role in consumption pattern formation in the sustainability direction. According to the numerical analysis, consumption and production patterns are coincided to some extent. This way, supply chain managers can be main contributors in determining a health consumption pattern by applying a proper production plan. Improving public awareness on organic product benefits for health and the environment results in improving the substitution rate of organic products for conventional (γ). Promoting organic products by reducing selling price or developing discounts for low-income persons/families, as well as applying high-performance methods in organic agriculture, improve γ too. Therefore, not only shortage cost is reduced, but also waste volume is lowered, especially for organics. From the long-term horizon, the costs of potential chronic diseases caused by conventional consumption, global warming, or climate change decreases as well.

The proposed model is extensive; future researches can be carried out with attention to the following aspects: i) studying various pricing policies for both organic and conventional products and regarding different classes of customers; ii) developing stochastic form of the model by considering uncertain demand, substitution rate, partial backorder rate, or deterioration rate; iii) calculating variety in transportation vehicles in terms of capacity, GHG emission, equipment, cost. This way, the economies of scale can be considered to determine transportation policies. Fourthly, the public health function has been defined in a linear form. Defining this function more exactly and based on statistical data also merits future research.

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